HARD PHOTON PRODUCTION IN NUCLEUS-NUCLEUS COLLISIONS AT 30 MeV/u AND 44 MeV/u

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JOURNAL DE PHYSIQUE
Colloque C4, supplément au n° 8, Tome 47, août 1986

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Résumé - Les sections efficaces doublement différentielles de production du rayonnement de Bremsstrahlung ont été étudiées pour les réactions $^{40}Ar + ^{197}Au$ à 30 MeV/u et $^{86}Kr + ^{12}C$, Ag_{Nat}, ^{197}Au à 44 MeV/u. L'analyse qualitative des caractéristiques de l'émission γ observée suggère fortement que les premières collisions neutron-proton constituent la principale source de rayonnement.

Abstract - Doubly differential cross-sections for Bremsstrahlung production have been measured in the reactions $^{40}Ar + ^{197}Au$ at 30 MeV/u and $^{86}Kr + ^{12}C$, Ag_{Nat} and ^{197}Au at 44 MeV/u. A qualitative analysis of the characteristics of the γ-ray emission suggests strongly that the initial proton-neutron collisions are the main source of nuclear Bremsstrahlung.

I - INTRODUCTION

Experiments on high energy photon production in nucleus-nucleus collisions have been reported very recently /1,2,3/ and different reaction mechanisms have been proposed to predict the production rate and the shape of the γ-spectra /4,5,6,7/. In an effort to increase our knowledge in this new field we have studied the $^{40}Ar + ^{197}Au$ reaction at 30 MeV/u and $^{86}Kr + ^{12}C$, $^{86}Kr + Ag_{Nat}$ and $^{86}Kr + ^{197}Au$ at 44 MeV/u. The ^{40}Ar projectile was provided by the SARA facility and the ^{86}Kr by the GANIL facility.

II - EXPERIMENTAL METHODS

The experimental set-up consisted of two identical detectors ; one was placed at the fixed angle $\theta_{LAB} = 90°$ and the other was used to explore angles between 40° and 160°. The fixed detector was used for monitoring and, also, to obtain improved statistics at 90°. Each detector consisted of one active converter (10mm BaF2) and two (or three) plastic scintillators (2mm NE102) used to identify the electrons and positrons of the shower and a large volume 15 x 20 cm NaI(Tl) scintillator. The detection system was completed by a veto plastic scintillator to eliminate charged particles entering the detector and a TOF measurement (BaF_2-RF) to eliminate neutrons. The γ-ray energy calibration was done with tagged photons produced at the SACLAY Linac. The γ-ray detection efficiency, which is the probability of producing a shower in the converter was computed with the EGS simulation code. The detection system has a low energy threshold of approximately 20 MeV.

III - RESULTS

Fig. 1 shows the γ-ray energy spectra observed at three laboratory angles. It is apparent that the spectra have an exponential shape and their relative hardness increases as the angle decreases. On the other hand the cross-sections decreases smoothly with angle showing no apparent quadrupolar behavior. It is, therefore tempting to explain the data by an isotropic center of mass (c.m.) γ-ray distribution of exponential shape :

$$\left[\frac{d\sigma}{dE\ d\Omega}\right]_{CM} \equiv K\, e^{-\frac{E_{c.m}}{E_o}}$$

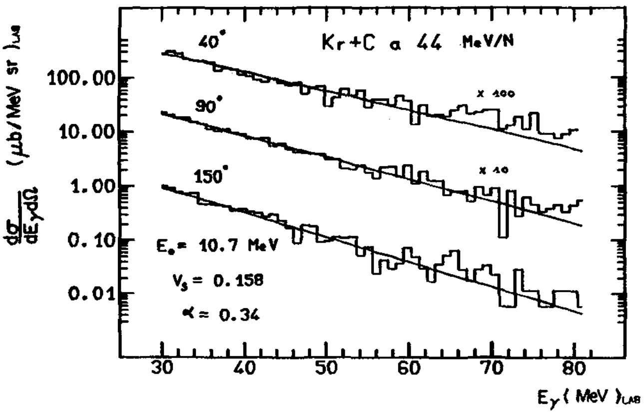

Fig. 1 - Energy spectra of high energy photons detected in the reaction ^{86}Kr + ^{12}C at 44 MeV/u. The lines have been calculated with eq.(2) of the text.

However a closer inspection shows that a better fit to the experimental data is obtained if one assumes that a part of the emission is anisotropic, with an E1 character. We have made the crude approximation that the source velocity (V_S) and the slope (E_O) are identical for the isotropic and anisotropic component. The amplitude of the anisotropic component has a large incertitude due to the lack of measurement below 40°. The cross-section relations used for the fit are :

$$\left[\frac{d\sigma}{dE\ d\Omega}\right]_{CM} = K\, e^{-\frac{E_{c.m}}{E_o}} \left(1 - \alpha + \alpha \sin^2 \theta_{c.m}\right) \qquad (1)$$

$$\left[\frac{d\sigma}{dE\ d\Omega}\right]_{Lab} = \frac{K}{X}\, e^{-\frac{E_{Lab}X}{E_o}} \left(1 - \alpha + \frac{\alpha \sin^2 \theta_{Lab}}{X^2}\right) \qquad (2)$$

with $X = 1 - \frac{V_s}{c} \cos \theta_{Lab}$

and the results are reported in Table 1.

Several aspects of the γ-ray emission can be deduced from these experiments :

- The γ-energy spectrum has an exponentially decreasing shape. The slope parameter E_O decreases as the incident ehergy decreases and is nearly independant of the target in Kr induced reactions.
- The velocity of the γ-source in the collisions of asymmetric nuclei is very close to that of the nucleon-nucleon c.m.
- In the source c.m. the angular distribution is mainly isotropic. A small anisotropic E1 component of $\sim$25% relative amplitude was tentatively deduced but no E2 component was evidenced. A similar result has recently been found by Grosse in C+C reaction at 60 MeV/u.

III - INTERPRETATION

The γ-ray production in nucleus-nucleus reactions and in p-nucleus reactions /8/ present several similarities. In both cases the γ-spectra have an exponentially decreasing shape and the γ-source velocity is close to that of the nucleon-nucleon c.m. Although no E1 isotropic component was found by the authors of ref./8/, we have deduced an amplitude α = 0.16

$\pm$ 0.10 for this component, from a new examination of the previously studied p-C reaction (Table 1). All these features have already been explained by assuming that the γ -rays, in p induced reactions, are produced in the initial p-n-collisions /9/. This hypothesis is in good agreement with the fact that the γ cross-section, for different targets, is proportional to the number of expected initial p-n-collisions.

The similarities between p-nucleus and nuleus-nucleus reactions suggest strongly that the origin of the Bremsstrahlung radiation is the same in both cases. In order to verify this assertion we have shown in Fig. 2 that the cross-section is proportional to the number of initial collisions, in Kr induced reactions, at 44 MeV, for C, Ag and Au targets. The number of p-n-collisions have been computed with a simple equal participant model /4/. Calculations are however needed to confirm this first collision hypothesis and especially to test the variation of the slope parameter E_0 with the bombarding energy.

System	E_i MeV/u	E_0 MeV	α	V_s/c	$V_{Beam}/c/2$
Ar + Au	30	7.3	0.	0.123	0.126
Kr + C	44	10.7	0.34	0.158	0.153
Kr + Ag	44	11.8	0.15	0.174	0.153
Kr + Au	44	11.3	0.28	0.138	0.153
mean value	44	11.3 $\pm$0.6	0.26 $\pm$0.10	0.157 $\pm$0.019	0.153
p + C	140	20.2	0.16	0.31	0.27

Table 1 - Least square fit parameters calculated with eq.(2). A mean value of the parameters for the Kr induced reactions on the three different targets is also given.

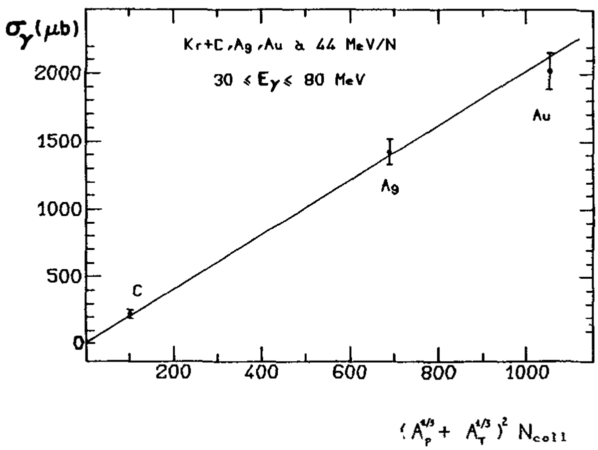

Fig. 2 - Total cross-section for Bremsstrahlung production with 30 $\lesssim E_\gamma \lesssim$ 80 MeV as a function of the product of the geometrical cross-section by the number of initial collisions (Ncoll). The line is drawn to guide the eye.

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